SOIL PHYSICAL PROPERTIES AS

AFFECTED BY NITROGEN AND BIOCHAR

AMENDMENTS

By

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Abstract: Biochar in combination with selected inorganic and organic sources of nitrogen is receiving attention due to its ability to promote crop yield and stabilize the soil. A greenhouse experiment was carried out for two years resulting in two seasons of planting to investigate the effects of biochar in combination with alfalfa, chicken manure and sterile chicken manure on wheat yield as well as soil physical properties such as: water percolation rate, bulk density, aggregate distribution and crust penetration resistance. The results showed that ammonium nitrate treatment had the highest yield when combined with biochar with an average of 2.73gplant^{-1} for the second and third season. Chicken manure had the lowest bulk density 0.76 g cm^{-3} and 1.17 g cm^{-3} for season 2 and 3 respectively). The research also indicated that ammonium nitrate had the highest percolation rates of 341 ml min^{-1} and 21 ml min^{-1} when combined with biochar for seasons 2 and 3, respectively.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

GENERAL INTRODUCTION AND LITERATURE REVIEW

Wheat Production and Global Climate Uncertainty.

Wheat (*Triticum aestivum* L.) is an important food crop consumed and cultivated all around the world. In 2016/2017 wheat production was 775 million metric tons making it the second largest cereal crop produced in the world in terms of gross weight production after corn (Wrigley & Wrigley, 2009). The United States is the fifth largest producer of wheat in the world and Oklahoma accounts for a fifth of that production. Winter wheat is planted on six million acres of farmland annually in Oklahoma (OCCES 2018). Wheat is consumed by billions of people all around the world for the high level of nutrition inherent in its grains. It is also used in pasta, bread, baked foods, alcoholic beverages, livestock feed, industrial alcohol production, explosive and synthetic rubber manufacture and many others.

Wheat grown in Oklahoma is almost exclusively hard red winter wheat. The USDA reported that between 2013-2017 the percentage of seeded wheat acres in Oklahoma allotted to the cultivation of hard red winter wheat stood at 97.4%, soft winter wheat 0.8% and unspecified wheat types at 1.8% (USDA-ERS2017). Wheat in Oklahoma is cultivated for forage only, grain only and for both forage and grain (Vocke & Ali, 2013).

The United States Department of Agriculture (USDA) classified wheat produced in the United States into five categories: hard red winter, hard red spring, soft red winter, white wheat (soft or hard) and durum wheat. The wheat production belt span from Montana, North Dakota, Nebraska to Kansas, Oklahoma, Texas where hard red spring and winter wheats are typically grown. In 2016/2017 growing season 820 million bushels of winter, spring and durum wheat on 50.2 million acres were produced in the USA. The states of Kansas and North Dakota are the leading producers of winter wheat which account for 75% of total wheat production in the United States. Oklahoma comes fifth behind Washington and Montana in total wheat production (Westcott 2010).

World-wide production is led by China, India, United States and Russia which together produces 50% of the world's wheat. Production and consumption of wheat is rapidly becoming popular in developing countries in Asia, Middle East and North Africa (Hancock, 2012) leading to increased demand.

The United States is the world's largest wheat exporter, but due to increased production elsewhere demand for US wheat has dropped by 10-25% from 2001 to the present. Wheat yields have steadily increased while total acreage has declined between 1998 to 2017 leading to a slight decline in overall production. The highest yield on record for the USA was in 2016-2017 where US farms produced an average yield of 52.7 bu ac^{-1} in contrast with the lowest recent yield of 35.0 bu ac^{-1} in 2002-2003. Historic yields before the introduction of advanced farming practices and genetics hovered around 10 to 15 $buac^{-1}$ (USDA 2018). Harvested acres declined from a high of 62.8 million acres in 1997/1998 to a recent low of 37.6 million acres in 2017/2018. This reduction in planted and harvested acres is largely due to low wheat prices, economic competition with other more profitable cropping systems like corn, soybeans and more recently cotton and changes in government policies (USDA 2018).

Production is typically sustained by synthetic inputs that add significantly to the production costs and cause some concern for the environment. Wheat agriculture in Oklahoma, USA and throughout the world has used relatively inexpensive inorganic fertilizers to maximize yield and economic potential for many years since inorganic forms became available. (Celik, 2004). In the United States, research into organic wheat production systems is advancing and some producers may shift to organic production, motivated by nutritional and environmental concerns, and by a premium price that is significantly higher than conventionally produced wheat. The economic motivation for organically produced wheat is usually offset by higher production costs, regulatory requirements and a yield penalty of around 25% (Pimentel et al. 1983).

Climate change poses a threat to future wheat production (IPCC 2014). The intensity and effect of climate change will likely differ across countries and regions, but will generally result in increasing temperatures and a reduction in the availability of water for agricultural production (IPCC 2014). Regions in the world which exist on the margins of agricultural productivity are especially threatened, especially the countries in Sub-Sahara Africa. Climate uncertainties coupled with an increasing population growth requires that we address these uncertainties by increasing wheat productivity not only in developed countries but world-wide at the same time as we seek to maintain the health of our soil environments.

Importance of Soil Structure to Crop Production

Soil structure is one of the most important physical properties that determines the overall health and productivity of a given soil system. Good soil structure is fundamental to processes that encourage healthy root development and improved soil microbial community structure and diversification. Soil microorganisms are involved in the recycling of nutrients and minerals like phosphorus, nitrogen and potassium along with the mineralization of soil organic matter. Moreover, soil microbes directly contribute to soil structure by producing glycoproteins that cements soil particles and organic matter into relatively stable soil aggregates. Soil macro organisms such as earthworms, ants and arthropods burrow into the soil creating structural pathways that ease the movements of water, air, minerals and other organisms

Soil structure is defined as the spatial arrangement of particles and associated pores in soils at different spatial scales ranging from nanometers to centimeters (Johnson et al. 2016). It is important that structural stability be added to this definition as soil structure is dynamic and is consistently influenced by changes in water content, synthetic fertilizer application, tillage and many other factor that could put stress on the soil system. Soil structure is also related to the stability of soil aggregates. Aggregates are formed by soil particles being cemented by organic compounds excreted mainly by microorganisms in conjunction with soil organic matter and clay minerals during the wetting and drying of the soil system (Cui, Askari, & Holden, 2014). There has been a lot of confusion in literature with regards to the difference between aggregation, soil structure and stability. In most cases the factors responsible for the formation of soil structure may differ from those responsible for the stability of soil structure with formation taking place before stabilization. While in a few instances factors responsible for aggregate formation are similar with those responsible for aggregate stabilization with both processes occurring simultaneously (Brussaard and Kooistra 2013). Furthermore, the formation of good soil structure depends partially on the particle size of soil minerals along with the organic matter content of the soil.

Arshad et al. (1999) indicated that microbial activity plays a greater role in the stabilization of structure than in its formation. In sand, structure is reflected in the pore distribution created by the relatively large size of the sand particles and the packing and rearrangement of sand particles through tillage or compaction. The structural arrangement of sandy soils is also influenced by living organisms such as earthworms, termites, bugs, ants and millipedes. Biological activities are mostly responsible for the formation of soil structure in sand as the structure is not significantly altered through drying and wetting process given that the shrink-swell capacity is practically zero in sandy soils (Arshad et al. 1999). In addition, sandy soils often contain a limited amount of soil organic carbon (SOC) in the form of microbes, plant and animal residue and their secretions. SOC influences structural formation through the bonding of primary soil particles. The effectiveness of SOC in the formation of stable aggregates is dependent on its decomposition rate, which in turn is influenced by activities of microorganisms (Arshad et al. 1999).

Soil aggregate stability can be improved through the addition of green and animal manures. The combinations of inorganic fertilizers with soil amendments, including plant and animal based manures have the potential to mitigate against the negative effects of inorganic fertilizer use on soil structure. In general, to maintain stable soil aggregates it is important that crop management practices are designed to include the application of organic carbon to the soil. The long term goal is a soil that is rich in organic matter, well aerated and structured, and able to support the ability of plant roots to explore and extract available water and minerals necessary to support the growth of crops.

Methods of Measuring Soil Structure

Soil structure is a broad term relating to the arrangement of soil particles in a unit volume of soil, including pore space, macroporosity and aggregate distribution. Soil structure measurement is used to determine the effects of agricultural practices such as tillage, organic matter additions and erosion on soil structure (Loch, 1994). While soil structure controls a vast range of activities in the soil, the measurement of its stability or distribution may not be sufficient to predict the ability of a soil to sustain plant growth, determine the diversity and population of soil microbes and amount of soil water and air available for crop growth. Recently new methods to estimate soil structural characteristics have been developed, and these are typically divided into two areas depending whether one is interested in hydrological or agronomic properties of soils. However, soil structure is very difficult to quantify by any one measurement system. Typically, researchers' measure only selected components of soil structure. However, a better understanding of factors that influences soil structural properties will give insight into the role of these factors in maintaining a balance between protecting the soil and the environment, and at the same time increasing crop production.

One component of soil structure is the presence of soil aggregates of varying size and distribution. Due to a wide range of complex reactions and variables that take place in the soil system which must be accounted for prior to analysis of soil structure, the measurement of aggregate stability and distribution can be complicated. Aggregate stability is often measured by the wet sieving method where soil aggregates are sieved through a series of screens under the gentle and defined agitation in an aqueous media. The level of stable aggregates is measured by determining the portion by weight of the soil sample that forms stable aggregates and particles smaller than the original or initial aggregate. The major problem is that the size distribution and stability under assay conditions must in some way be related to the same properties found in the field situation. This implies that the external forces operating under field conditions are similar in effect to the forces encountered during wet sieving in the field situation. However, it is clear that no single type of disintegrating force can be reliably used to arrive at a quantitative measure of soil structure (Joseph et al. 2010). The forces influencing aggregate stability in the field may be different from those experienced under the wet sieving method, and the multiple forces and their interactions acting in the field cannot be measured independently of each other. The stability of the aggregates in the wet sieving system is associated with the collision energy between aggregates and sieve. Ideally, while the properties of aggregate stability could be defined on a fundamental physical basis in the same way hydraulic conductivity can be defined in terms of displacement and flux, or bulk density as an index of solids and pore spaces, interpretation of wet sieving results may provide at best an approximation of the level of aggregate stability

Measurement of aggregate stability can be done using a variety of methods including the wet sieving method, dry sieving method, saturated hydraulic conductivity method, the clod shrinkage method, the clay index of soil deformation method, self-mulching method and lastly, the manual and visual method (Coughlan, Mcgarry, Loch, Bridge, & Smith, 1991) For our purposes here we will restrict our analysis to the most commonly used method which is the wet sieving method, the method used in our analysis. Samples are taken from the pot or in the field using a flat-head spade like tool being careful to not disturb inherent soil structures. Samples should be transported in rigid containers to avoid the breakdown of aggregates and compression of particles. Soil water content before sieving is a major influence on measured stabilities. For this reason, it is recommended to air dry the soils prior to sieving. Drying of aggregates should be done at room temperature or that representative of field conditions. Samples that have been disrupted during transportation or collection are typically unstable and the process of oven-drying actually increases their stability in otherwise unstable aggregates, resulting in artifacts.

Effects of Current Production Practices on Soil Structure and Soil Health

Presently, wheat production practices are heavily dependent on the application of nitrogen fertilizers like, ammonium nitrate, anhydrous ammonia and urea. Application of sufficient N fertilizers have proven to be one of the most important factors that ensures economic yield. Wheat producers usually apply inorganic fertilizers without realizing the effect these have on the structure of the soil over the long term.   The application of inorganic nitrogen fertilizers over a long period has been reported to be associated with a decline in microbial biomass content (Ananyeva, Demkina, Jones, Cabrera, & Steen, 1999). Nitrogen fertilizers have been a driving force in improving agricultural production for many years. Inorganic fertilizers like urea, ammonium nitrate and anhydrous ammonia are the major fertilizers currently used by producers for wheat cultivation. Nitrogen is the nutrient that has the greatest impact on wheat growth and development. While organic nitrogen has been identified as one of the most abundant forms of nitrogen in the soil, it is not the most readily available form used by plants during the course of their growth and development. Plants use primarily inorganic nitrogen in the form of nitrate or ammonium ion, but not the organic nitrogen form, so organic nitrogen must first be converted to the inorganic form before it can be utilized. The predominant form of inorganic nitrogen in most agricultural soils is nitrate. Nitrates are highly soluble and can remain in the soil solution for a long time before they are either taken up by the plant, denitrified, or leached out of the rooting zone (Sebilo et al. 2013) . The second form of nitrogen comes in the form of ammonium ion. Ammonium ion based fertilizers are highly soluble and are rapidly absorbed to soil particles (Aldrich et al. 1945).

One problem with the use of inorganic fertilizers is the impact of nitrates from nitrogen fertilization on surface and ground waters resulting in a process termed eutrophication where fertilizer induced algal blooms reduces the oxygen levels in the water promoting anoxic conditions, creating ‘’dead zones” in water bodies, causing the death of many aquatic animals. Application of excessive inorganic fertilizers are responsible for a bulk of nitrate accumulation within the soil profile of croplands leading to groundwater contamination (Tilman et al. 2002; Cui et al. 2013). Researchers have reported that water in creeks and rivers from Michigan to Puerto Rico are heavily polluted with nitrates from commercial fertilizers. In China, widespread soil acidification has been reported following application of excessive amounts of nitrogen fertilizer not taken up by the crop, resulting in high concentration of nitrogen which reaches surfaces water via drainage and flows to nearby lakes and streams which are sources of drinking water for the local farming community. Moreover, nitrates in the ground water may contribute to a possibly fatal disease in infants called methemoglobinemia, or "blue baby" disease (Bucklin 1960). To effectively balance increased crop production while protecting environmental and human health, concerned scientists have questioned our dependence on nitrogenous fertilizers to sustain crop yields (Tilman, Cassman, Matson, Naylor, & Polasky, 2002).

The reduction in enzyme activities of microbes due to the acidifying effects of nitrogen fertilizers also results in soils that are low in organic matter. These microbial activities are important in the breakdown of dead plant residues as well as plant nutrients needed for plant growth and also the survival of the microbes. The absence of these activities will result in a poorly structured soil that is easily dispersed during high rainfall (A., Belay, Claassens, & Wehner, 2002). The study corroborated that long term application of inorganic fertilizers deteriorated soil structure, soil organic carbon, bulk density, water-holding capacity and saturated conductivity. The application of inorganic fertilizers for 12 years significantly decreased aggregate stability and macro porosity by 55.3 and 36.1 %, respectively (Zhou et al. 2017). Long term application of synthetic fertilizers impacted negatively on the spatial organization of soil particles and compacted pore spaces between them (Peng, Horn, & Hallett, 2015).

Alternative Wheat Production Practices

Prior to the passage of the Organic Foods Production Act of 1990 by the United States Congress, the U.S. had less than a million acres of USDA certified organic farmland. Since then the demand for organic crops and livestock has increased, and this has been followed by the USDA establishing regulations of agricultural practices related to organic production (Francis, 2016). These regulations ensure that food labeled as organic are indeed produced under organic conditions. However, the regulatory burden often inhibit farmers from adopting organic practices due to the effort and cost associated with these practices. Even though certified organic farmland had increased from less than a million acres to 3.1 million acres between 2005 and 2011, this is only a miniscule 0.8% of total farmland, and was only 0.6 % of total wheat acreage, while corn and soybean were 0.3 % and 0.2%, respectively. Though total wheat production occupies the most acreage of any other crop, the adoption of organic practices has not matched the demand for the crop (USDA ERS - 2016). This has led to a significant premium price paid for organic wheat that at times can be triple the amount offered for conventional wheat. Despite the price incentive, wheat farmers are still reluctant to adopt organic practices.

A movement toward organically produced wheat essentially prohibits the use of inorganic fertilizers, relying instead on plant and animal sources for nitrogen. Under organic production, significant levels of organic carbon and nitrogen are incorporated into the soil medium. The organic system of wheat farming differs significantly from the conventional wheat cultivation as it eliminates the use of genetically modified seeds, inorganic fertilizers, and pesticide. Some organic producers also practice no-till cultivation, depend on crop rotation to control weeds and manipulate planting and harvesting dates to protect wheat yield. Biological control of wheat pests are also considered by organic farmers instead of using pesticides (McBride, Greene, Foreman, & Ali, 2015). Organic cultivation of wheat has the potential to address some of the most serious environmental problems associated with conventional agriculture like soil acidity, water pollution, erosion, human and animal exposure to toxic materials, to name a few. It is a general belief that the practice of organic farming has minimal negative effects on the soil environment as it does not involve the use of conventional chemical fertilizers and herbicides

Plant and Animal Sources of Nitrogen and their Effects on Soil Structure

While an increase in crop yield has been linked to the use of inorganic nitrogen fertilizer, the long term consequences of the use of inorganic nitrogen fertilizers on overall soil health range from a compacted, highly acidic and poorly structured soil to environmental pollution of groundwater. To mitigate these effects, researchers have focused on the use of organic sources of nitrogen for crop production or in combination with controlled proportions of nitrogen fertilizers. The later split treatment is practiced to create a more balanced soil system, such that yield goals are met while at the same time improving the physical properties of the soil. Adding plant and animal manures leads to an increase in soil organic matter over time and can have a positive effect on reducing the need for synthetic fertilizers. Green and animal manures provide nitrogen, promote the build-up and formation of organic matter, improves soil structure, encourage the movement of water and oxygen throughout the soil profile, which results in a more growth promoting environment for crops. Furthermore, the nitrification process converts manures to available nitrogen needed to promote plant growth and development. Organic fertilizers have been reported to affect the organic matter content ultimately improving soil physical properties and are a major determinant of the soil structural stability (Golueke 1999).

Animal-based manures from chicken, cattle, horse, or pig are major organic forms of nitrogen used in organic production systems. They are richer in nitrogen when compared to green manures and are decomposed more quickly into plant usable nitrogen forms. In addition, bone and blood meals have also been used as slow release organic fertilizers, but mostly in a horticultural setting (Bøen and Haraldsen 2013). All animal manures have the potential of carrying human and plant pathogens to a certain extent. To avoid transfer and accumulation of disease causing agents into the field these fertilizers may be cured by drying followed by field application months before planting. Chicken manure is the one of the most widely used forms in areas where poultry farming is typical. Chicken manure is high in humic acids which are important long term structural components of stable soil systems (Mbagwu & Mbah, 1998). Chicken manure also aides in the remediation of acidic soils over the long term, adds organic matter and increases water holding capabilities of the soil (Hue, 1992). Furthermore, the organic matter content provided by chicken litter has proven to increase soil electrical conductivity (EC) (Eghball, Ginting, & Gilley, 2004). EC is a measurement that may be correlated with crop productivity, soil texture and structure, cation exchange capacity and even how water moves within the soil profile. Chicken manure is also rich in organic nitrogen which is slowly released over time. Researchers have found that the application of chicken manure improves bulk density, soil porosity, water holding capability and water percolation (Agbede, 2006; Eghball et al., 2004). The percolation of water has also been reported to improve when chicken manure is applied due to the hydrophobic nature of chicken manure (Mbagwu & Mbah, 1998). This research concluded that the application of chicken manure ensures the stability of soil structure, improves soil organic matter content, crop yield and nutrient availability (Agbede, 2006; Eghball et al., 2004).

Green manures come in the form of plant materials containing a significant level of nitrogen, and are often produced from leguminous crops or meals derived from corn, soybeans or other crops (Celik, 2004). Green manures are typically applied as incorporated cover crops like groundnut, millet, sorghum, cowpea, leguminous plants like alfalfa, clover, peas and beans. However, some green manures come in the form of dried biomass from previously harvested crops, to bedding and mulching materials such as sawdust, wood chips, straw or hay and peat moss. Legumes contain nitrogen-fixing bacteria in their root nodules that makes nitrogen available for plant use. Nitrogen laden plant materials provide slow release forms of nitrogen that can sustain subsequent plant growth for a significant period of time. Moreover, these agents have the ability to insulate the soil and stabilize soil temperature to support growth and development of crops as well as microorganism. Addition of green manure increases organic matter content, improves overall soil structure and increases the water holding capacity of the soil medium (Golueke 1999). Unfortunately, green manure materials are composed primarily of carbon subject to microbial mineralization and therefore tend not to sustain the amount of soil carbon over the long term (Turk and Partridge 1947)

Alfalfa green manures has also been reported to improve soil physical properties, however, very little is known about its effect when applied below and above the soil. the Alfalfa plant has roots that can penetrate deep within the soil profile thereby bringing up nutrients unavailable for shallow-rooted plants. The application of alfalfa root and shoot significantly improved soil aggregate stability, water flow, soil porosity and the saturated hydraulic conductivity (Rasse, Smucker, & Santos, 2000). Previous studies have also reported an improvement in soil structure when dried alfalfa was incorporated as the only source of soil amendment, and also when combined with other organic sources such as wood pellet, cow dung and chicken manure (Angers, 1992; Chantigny, Angers, Prévost, Vézina, & Chalifour, 1997).

The application of crop residues or green manure have been proposed as an alternative practice of providing needed nitrogen for crop production (Drinkwater, Wagoner, & Sarrantonio, 1998). While the long term effects of green manure on soil properties is still being investigated and discussed, there has been evidence to show that composted green manure can be used for the amendment of poorly structured soils, however, when used as a major source of crop nutrients, crop yield is usually lower compared to animal manure when practicing organic farming (Liu, Lu, Cui, Li, & Fang, 2014; Powlson, Glendining, Coleman, & Whitmore, 2011)

Biochar and its Effects on Soil Structure

Soils used for agronomic purposes typically have a limited amount of carbon, usually between 0.5 to 2% of the total weight of the soil. Of the organic matter added to the soil, 45% comes in the form of carbon (Schlesinger and Bernhardt 2013). Soil carbon has a major impact on soil structure and soil health. Soil health, or quality, can be broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran 2002).

Once soil carbon is applied half is lost through respiration within the first few months after application (Sohi et al.2010). The other half is then slowly respired away over time with little remaining to build up the soil carbon reserves. Most recent advances in soil amendments have shifted to the production of carbon sources that are more stable over the long term. Addition of a stable form of carbon can also improve productivity, and promote beneficial interactions between physical, chemical and biological systems. Stable carbon can be used in altering, moderating and managing physicochemical properties of soils ranging from cation exchange capacity (CEC), soil nutrition, nutrient use efficiency (NUE), microbial activities, water retention and infiltration (Singh, Camps-Arbestain, & Lehmann, 2017).

Biochar is a very stable form of carbon and a soil remediation tool that has been used for a long time in indigenous farming systems as a soil additive to enhance the soil nutrient holding capacity, especially in soils where leaching is a major problem (Sohi et al. 2010). Biochar is rich in stable carbon and when applied to the soil can remain for thousands of years. It is produced through the thermal decomposition of biomass with and without the exclusion of oxygen at temperatures between 300 -750^{o} C. (Sohi, Krull, Lopez-Capel, & Bol, 2010). The method of preparation of biochar and the source from which biochar is produced can affect many biological, chemical and physical interactions in the soil and its effectiveness as a soil amendment or conditioner (Sohi et al. 2010). Biochar sources range from farmyard animal manure like chicken litter, to plant biomass chicken like rice husk, to industrial waste from paper mill, hardwoods and softwood. Biochar has been reported to improve the structure of a soil by improving the water-holding capability of soils (Glaser, Lehmann, & Zech, 2002; Sohi et al., 2010). The application of biochar to soils has been reported reduce bulk density and increase crop yield (Sohi et al., 2010). Biochar has been shown to help soil clods to hold cations tightly to the surface thereby modifying the structure of a soil to hold water and reduce the leaching of plant nutrients (Glaser et al., 2002; Marris, 2006). This further explains why soils treated with biochar have a higher volumetric water content compared to soil that were not treated with biochar (Sohi et al., 2010)

Even though there is limited information on the ability of biochar to independently support crop growth, recent studies in the past decade have started to combine biochar with inorganic nitrogen fertilization with the purpose to mitigate the long term effect of inorganic fertilizer (Sadaf et al., 2017). Here we investigated the impact of organic nitrogen amendments from a plant and animal source and biochar on wheat productivity and the resultant changes in selected soil physical properties over two seasons of wheat growth and development (Sohi et al. 2010)

CHAPTER II

SOIL PHYSICAL PROPERTIES AS AFFECTED BY NITROGEN AND BIOCHAR AMENDMENTS

INTRODUCTION

The dramatic growth in world human population requires an increase in food production to avoid famine, and economic and political turmoil. To meet these increasing food demands will require an increased food production for a given unit of land. To do this will likely require an increase in the application of inorganic nitrogen fertilizers world-wide. However, addition of excess fertilizer to the soil can seriously impact soil health and structure. The question is if we can develop alternative management practices that avoid such complications.

Alternative forms of crop production such as the use of organic farming methods are increasingly becoming popular and economically viable. Organic wheat cultivation prohibits the use of inorganic fertilizers and synthetic chemicals for crop protection. This system encourages the use of organic forms of fertilizers that are more compatible with soil biology (Anna et al., 2018). The use of organic farming practices can have dramatic effects on soil structure and health through the increase in soil organic carbon. Added soil carbon is a major factor in the improvement of soil structure and soil health (Sohi et al., 2010).

Alternative practices such as the use of biochar combined with organic sources of nitrogen like chicken manure and alfalfa meal are likely to promote improved soil conditions for adequate plant yield, at the same time protecting the soil environment. Here we examined the effect of various amendments including organic and green manure over several seasons of plant growth and development on measured physical attributes of the soil. In addition to the amendments mentioned above we examined the effect of biochar, a stable form of carbon derived from pyrolysis of plant or animal waste, on selected soil structure measurements and their interaction with the organic and inorganic forms of fertilizers.

The soil structure controls a wide variety of important activities that takes place within the soil profile. A well-structured soil is friable, rich in organic matter and minerals, has the ability to hold water, generally has relatively low bulk density and exhibits a relatively high ability to infiltrate water and air throughout the soil profile. Soil physical properties are vital in encouraging crop growth and development. Of all the factors mentioned above, application of organic fertilizers has been reported to be one of the important factor that affects the soil physical properties (Šimon and Czakó 2014). Organic fertilizers serve two major purposes in the soil: they serve as sources of soil nutrients and as sources of soil carbon.

Typical cultivated soils in Oklahoma have a limited amount of soil carbon (OCC, 2011). Adding carbon in the form of green and animal manures over time will result in increased soil carbon (Schlesinger & Bernhardt, 2013). However, green and animal manures are easily degradable over time without substantially contributing to the stable carbon soil reserve. Recent advances in cropping system managemen have investigated the use of stable carbon sources such as biochar. Biochar is a soil remediation amendment that has been in use by indigenous peoples for thousands of years to improve the nutrient holding capacity of their soils. In contrast to manures, biochar is a stable form of carbon that is produced by the pyrolysis of crop or animal residues at temperatures between 300 -750^{o} C. Biochar in ways unknown is also capable of improving the physical, chemical and biological properties of soils, including: cation exchange capacity, water retention and infiltration , nutrient retention, organic matter content, microbial activities and populations, and nutrient use efficiency (Singh et al., 2017). Even though there is limited information on the ability of biochar to independently support crop yield, recent studies in the past decade have started to look at the combination of biochar with inorganic nitrogen fertilizers (Sohi, 2010).

The objective of this project is to determine the effect of an inorganic fertilizer (ammonium nitrate), an animal manure (chicken manure), green manure (alfalfa meal), and biochar over three seasons of growth and development on wheat yield and soil physical properties.

CHAPTER III

METHODOLOGY

Experimental site and Management

Spring wheat variety Brick was planted in a Kirkland B soil, classified as fine, mixed, super active, thermic Udertic Palseustolls, and collected from a field with a long history of wheat production at Stillwater Agriculture Experiment Station. The parent material is predominantly a clayey mantle over shale from the Permian age. These soils are very deep and well drained (Fisher, 1969). Soils were collected from a depth of approximately 0-15 cm and then transported to the USDA greenhouse in Stillwater. A nutritional analysis was carried out by the OSU Soil, Water and Forage Analytical Laboratory (SWFAL) to determine the plant available nitrogen (N), phosphorous (P) and potassium (K). Initial nutrient analysis prior to planting indicated that the soil contained on average 28 kg/ha N, 52 kg/ha P, and 671 kg/ha K. The soil had an average pH of 6.6. Biochar (Wakefield Biochar, Columbia, MO) was also tested for its NPK content (0.36% N, 0.16% P, and 0.19% K). Inorganic nitrogen treatments were supplied with ammonium nitrate fertilizer (34% N). Dehydrated Hoffman Super Manure was used as a nitrogen source (Good Earth Horticulture Inc, Lancaster, NY) containing 2.8% N, 2.2 % P, and 3.3% K. Organic alfalfa meal (Down to Earth, Eugene, OR) as a green manure source of organic nitrogen contained 2.9% N, 0.22% P and 2.0% K. All nutrient additions were adjusted to meet targeted NPK levels (89 kg/ha N, 168 kg/ha P, and 493 kg/ha K) inclusive of the NPK from the amendments. Biochar was added at 1% of the soil air dried weight.

Wheat was planted in a Tray 10 plastic box (Stuwe and Sons Inc, Tangent, OR) (33 cm wide and long and 10 cm deep) lined with a plastic bag and containing 25 kg of Stillwater Farm soil in both the Fall of 2016 and Spring of 2017. Prior to loading into the containers, the soil was mixed in a cement mixer for 10 minutes during which nutrients were added to meet the targeted nutrient levels. The mixed soil was evenly distributed across the Tray 10 containers until completely filled to normalize the soil growth environment across experimental units. Containers were randomly distributed in the greenhouse space and shifted multiple times in order to reduce growth environment variance between treatments. A sterilized chicken manure treatment was added to gauge the effect of manure microbes. Sterilization was accomplished by chloroform fumigation where an open flask of 30 ml of chloroform was added to a sealed Mason jar containing nonsterile chicken manure for 4 days. In total, there were 8 soil treatments: 4 nitrogen form treatments as mentioned above with and without biochar. Each treatment was replicated 3 times for a total of 24 experimental units.

The experiment was carried out in the greenhouse during the fall and spring of 2016 and spring 2017 under moderated environmental conditions, with temperatures ranging from 10º to 30º C and with 14 hours of supplemental lighting. A hard spring wheat variety Brick obtained from the South Dakota State University wheat breeding program was used in all experiments. Brick wheat was chosen due to its fast maturity and resistance to Fusarium head blight (Glover et al., 2010). Seeds were planted to a depth of 1 inch. A total of 9 plants were grown in each Tray 10 box. There were two seasons of planting with the first seasons of growth and development in the fall of 2016 and the second season in the spring of 2017. Water was provided as needed to avoid stress as determined by a calibrated soil galvanometer readings according to manufacturer’s instructions (Spectrum Instruments). Grain and biomass were harvested at physiological maturity. Wheat biomass and grain was separated from chaff using a thresher (Precision Machine Co, Lincoln, NE), and were weighed with a milligram scale.

Soil Physical Property Measurements and Data Analysis

Soil physical properties were measured in each container after harvest. First soil surface hardness was determined using an E-280 pocket penetrometer (Geotest Instrument Corp, Burr Ridge, Illinois). This instrument is a spring type operated device with a narrow solid steel probe that manually penetrates the soil. A polished spring actuated piston measures the resistance by the soil matrix (Amacher & O'Neill, 2004). There were two measurements per containers for a total of 48 measurements.

Bulk density was determined based on weight measurements from soil cores. Soil cores were extracted using a chrome plated steel tube (3.8 cm diameter and 15 cm length) by manually pressing the tube down to a 5 cm depth. A total of two cores were extracted from each Tray 10 for a total of 6 cores per treatment. Fresh weights were determined and the cores were placed in plastic bags, transported to the laboratory and dried at 105° C for 24 hours (Donald C. Erbach & Erbach, 1987). After 24 hours the oven dried soil cores were weighed and the bulk density was determined as the weight of the dry soil over the soil volume.

Water percolation measurements were conducted in the same holes vacated by the bulk density soil cores by adding 90 ml of water to the hole and determining the time required for the water to drain to the bottom. The rate was calculated by dividing the volume of water by the number of seconds to drain.

Aggregate distribution was determined using the wet sieving method (Yoder, 1936). A hole was excavated into the soil to about 15 cm depth. A knife was used to carefully slice into the soil profile so as to not substantially disturb the soil aggregates and approximately 100 g of soil was weighed and placed in a paper bag and then air dried for 24 hours prior to measurement. The wet sieving measurements were carried out at the OSU Soil Physics Laboratory using screens of 4, 2, 1, 0.5 and 0.25 mm gauge assembled (top to bottom) in a stack. Preweighed soil samples were placed on top of the 4 mm screen, the stack was gently immersed into 19 liter bucket filled to within 5 cm from the top. The wet sieving machine initially soaks the soil for 10 minutes without mechanical agitation to complete the slaking process. After the initial period the screens were moved vertically at 30 cycles per minute for 10 minutes. When done the stacks were disassembled and the soil on each screen was washed off into a separate pre weighed drying can. The cans were dried for 24 hours at 105^{o} C and afterward weighed again when cooled. A total of two samples were taken from every Tray 10 for a total of 6 aggregate distribution measurements per treatment. The proportion of total soil weight as aggregates was determined by the dry weight from each sieve fraction divided by the total fresh weight of the soil prior to sieving.

All the data for all measurements were loaded into an Excel spreadsheet where basic statistics such as average and standard deviations were calculated. Results were statistically analyzed using SAS-JMP version 13.0 software. A completely randomized two factor nested design with biochar or no biochar as the main effect and nitrogen form as the subsidiary effect was used. Multiple comparisons among treatments were performed using Tukeys HSD with a significance level of $p \leq 0.05$.

CHAPTER IV

RESULTS AND DISCUSSION

Grain Yield and Nitrogen Amendments:

Wheat plants were grown under greenhouse conditions in plastic bins containing soil with a history of wheat production. The soils were amended with either biochar as a main treatment effect and ammonium nitrate, chicken manure and dried alfalfa meal as subsidiary effects. Seed weight data per plant for spring wheat treated with biochar and the different forms of nitrogen are presented in Figure 1. Overall there were no significant differences ($p \leq 0.05$) with or without biochar or with the inorganic and organic nitrogen sources for the first season of growth and development in the fall of 2016 based on analysis of variance (p value. 0.055). Seed weights per plant were highest in the ammonium nitrate and biochar treated plants compared to the other treatments.

Seed yield weights in wheat after the second consecutive treatment with amendments showed dramatic differences among nitrogen treatments in the spring of 2017 according to the analysis of variance (p value $\leq$ 0.0001). As in the fall of 2016 biochar addition did not statistically influence yield (p value, 0.25) nor was there a significant interaction between biochar and nitrogen form (p value, 0.41). There were highly significant differences among nitrogen treatments (p value $\leq$ 0.0001) where ammonium nitrate treated wheat yielded 2.7 fold greater than the average of the other three treatments. Ammonium nitrate, alfalfa meal and chicken manure all differed significantly from each other in terms of seed yield per plant with ammonium nitrate having the highest seed yield followed by alfalfa meal and then chicken manure treatments. Nonsterile and sterilized chicken manure did not differ statistically from each other, but sterile chicken manure showed the lowest seed weights per plant of all the treatments. The difference between the sterile and non-sterile treatments represents a measure of the effect of the contribution of manure microorganisms to wheat seed yield which appears to be negative.

The growth environment during the spring of 2017 was dramatically different from the other two periods in that the harvest was conducted later in the season when temperatures were much higher in the greenhouse. During this elevated temperature period the wheat plants were undergoing anthesis and grain filling, two of the most sensitive stages in determining final wheat yield. The differences between Fall of 2016 where the growth environment was comparatively mild to the Spring of 2017 where the growth environment was more stressful would suggest that temperature extremes have more effect on the organic treated plants than the inorganic treated under the conditions of this study. Alternatively, the second season of growth during the spring of 2017 represents a compounded effect of treatment over two seasons of growth and development. Thus the treatment effect may not have had time to express itself during the first season, but was more fully revealed in the second season of growth and development.

Bulk Density

Bulk density in soils is a measure of the weight of a given volume of soil. This measure is an important soil characteristic strongly associated with the root growth environment. High bulk densities due to compactions tend to restrict root growth. High bulk densities are also characteristic of course textured sandy soils. Lower bulk density soils provide more pore space for greater root aeration and tend to promote root growth and increase plant yield (Ola, Schmidt, & Lovelock, 2018). Bulk density values were analyzed after the addition of biochar and the various nitrogen fertilizer forms, and across two growth season in the fall of 2016 and spring of 2017(Figure 2). The bulk density data across seasons differed significantly from each other (p value $\leq$ 0.0001) and were analyzed separately.

In the fall of 2016 bulk densities averaged 1.05 g/cm^3 across all treatments and ranged from a high of 1.30 g/cm^3 in soils treated with biochar and ammonium nitrate to a low of 0.76 g/cm^3 in soils treated with sterilized chicken manure in the same period (Figure 2). Addition of biochar significantly decreased bulk density overall across all treatments from 1.15 g/cm^3 without biochar to 0.95 g/cm^3 with biochar. Thus biochar reduced bulk density during the fall of 2016. Biochar in combination with sterile chicken manure had the lowest bulk density of all treatments. During the fall of 2016 the two chicken manure treatments and the alfalfa treatment with biochar resulted in a significantly lower bulk density than ammonium nitrate with biochar and alfalfa meal and sterile chicken manure without biochar. Thus the presence of biochar resulted in an overall lowering of the bulk density in nonsterile chicken manure and alfalfa meal treated soils. This is consistent with findings where biochar combined with chicken manure lowered bulk density (Blanco-Canqui, 2017). This lowering contrasts with ammonium nitrate where the presence of biochar reduces the bulk density compared to the no biochar control, although the reduction was not statistically significant.

In the spring of 2017 bulk density values were more evenly dispersed across treatments in comparison to those from the fall of 2016. Overall bulk density values across treatments averaged 1.21 g/cm^3 with a high of 1.31 g/cm^3 for alfalfa meal without biochar and a low of 1.13 g/cm^3 with ammonium nitrate and without biochar. In contrast to the fall of 2016 there were no significant differences among treatments. The reason for the seasonal effect is not exactly clear but it seems that over time bulk densities increased significantly. Analysis of moisture content data indicated that moisture did not have a significant effect on the bulk density measurements across treatments. This may have been as a result of difference in temperatures across seasons. This contrasts with a study that concluded that "bulk density remained unchanged at constant temperature over a long period of time" (Lucia Korenkova & Urik, 2012). The increase in bulk density cannot be the result of soil settling over time since the soil was mixed extensively prior to planting in both seasons. The elevated temperatures during the spring compared to the fall treatments may have some effect on the overall bulk density measurements but how this could occur is not readily apparent. The lack of consistent treatment effect in this study makes interpreting the bulk density data problematic.

Penetration Resistance

Initial observations in previous experiments indicated that soils treated with ammonium nitrate (AN) were much harder than those with chicken manure (CM). Here we tested this observation by measuring penetration resistance (PR) using a pocket penetrometer in soil treated with biochar and the three nitrogen forms including ammonium nitrate and chicken manure. Penetration resistance across two seasons did not differ statistically (p value, 0.92). Thus overall PR data across seasons were combined

(Figure 3). The average PR across all treatments and seasons was 1.67 kg cm^{-2} with a maximum of 3.5 kg cm^{-2} for an ammonium nitrate treated soil without biochar and a minimum of 0.50 $kgcm^{-2}$ found in soils treated with sterile chicken manure (CMS) with biochar addition, a seven-fold difference. The addition of biochar did not significantly affect PR (p value, 0.30), but PR was significantly affected by nitrogen form (p value $\leq$ 0.0001). The nitrogen form treatments with the highest PR were the ammonium nitrate and alfalfa meal treatments averaging 2.14 $kgcm^{-2}$. The treatment with the lowest PR was the chicken manure and sterile chicken manure averaging 1.21 $kgcm^{-2}$. Ammonium nitrate with biochar and alfalfa meal with and without biochar differed significantly from the treatments with chicken manure. The results of the study confirmed the previous observations that treatments with ammonium nitrate results in harder soils as manifest by a higher PR compared to treatment with chicken manure. Previous research has shown that PR and bulk density were interrelated. Soils that have a high bulk density generally have higher PR (Celik et al. 2010). However, in this study there was minimal relationship between the two parameters (R^2, 0.07).

Percolation

Percolation resistance is a measure of how fast water moves through a soil medium. Here percolation was measured using a new customized procedure adapted to our minimal sized growth environment. This type of test is often used when constructing septic systems in order to determine infiltration rates. Here a small hole was created by the removal of a soil core and a defined volume of water (90 ml) was added to the hole. Percolation rate was measured as the volume of water divided by the time it takes for the water to drain to the bottom the hole expressed as ml min^{-1}. The average percolation rate across all treatments was 63 $mlmin^{-1}$ with a maximum of 341 ml min^{-1} recorded for ammonium nitrate (AN) treated soils with biochar in the Fall of 2016 and a minimum value of 8 $mlmin^{-1}$ recorded for sterile chicken manure (CMS) without biochar in the Fall of 2017 (Figure 4), approximately 42-fold difference. These large variations made it difficult to adequately distinguish among treatments. Measured values varied significantly across seasons (p value, 0.0027) most likely due to differences in soil moisture levels at time of measurement with average values at 71 $mlmin^{-1}$ and 113 $mlmin^{-1}$ for fall 2016, and spring 2017, respectively. Thus, results were analyzed for each season separately. The difference among season may have been due to variation in moisture content of the soil prior to measurement. While the moisture levels across season varied significantly, within season moisture levels among experimental units were very similar. Thus, comparisons within a season are more reliable in reflecting treatment effects.

In the fall of 2016, surprisingly there were no significant differences among any treatments including biochar and nitrogen form (p value 0.13) despite the wide variation in measurements (13.4 to 341.2 $mlmin^{-1}$). Again, the highest infiltration rate was associated with ammonium nitrate treatment with and without biochar while the lowest rate was associated with the sterile chicken manure. The high rate of infiltration in ammonium nitrate treated soils may have been due cracking and blocking in the soil profile permitting rapid soil flushing of water to lower depths. In the spring of 2017 there were significant differences among nitrogen (p value 0.011) form but not biochar additions (p value 0.28). Here again ammonium nitrate treatments with and without biochar showed the highest infiltration rates among all treatments. These differences were significantly different from the lowest treatment of sterile chicken manure without biochar. Thus ammonium nitrate treated soils showed the highest rates of water infiltration rates during both seasons. No other significant differences were evident. Percolation measurements were minimally correlated with penetration resistance (R^2=0.07) indicting a very minimal relationship.

The high variability in the data may have been due to a problem with how the measurement was conducted. Applying water to a dry soil, especially one with extensive secondary structure likely resulted in rapid movement of water through large cracks to lower levels. A better approach would be to infiltrate a known volume of soil with liquid medium through the soil, allow the water to reach the bottom of the hole, and then adding another volume of water to the soil. The first volume would act to seal the cracks and pores initially followed by another aliquot of water to measure infiltration rate in a way that better reflects the overall percolation rates of the soils. It is hypothesized that such an approach will dramatically reduce measurement variability.

Water-Stable Aggregate Distribution

Soil secondary structure is partially determined by the arrangements and size of water stable aggregates. Aggregated soil is formed mostly through the action of microorganisms which secrete a variety of soil binding compounds and proteins to cement soil together (Martin, 1946). The soil aggregate size distribution examines the distribution of aggregates in different size fractionation ranges from 0.25 mm to 4 mm diameters. Water-stable aggregate distribution was determined for fall 2016 as illustrated in Figure 5 since, unfortunately, the spring 2017 data was lost due to a computer accident.

Aggregate distribution in the fall 2016 season of growth showed significant differences with biochar addition (p value, 0.0008), nitrogen form treatment (p value < 0.0001) and distribution size (p value < 0.0001). Addition of biochar resulted in an overall increase in the soil aggregate average distribution weight equal to and above 0.25 mm values. There were no interactions between biochar addition and the individual distribution sizes. Therefore, based on a single season data it appears that biochar tends to increases soil aggregation by approximately 13% above the no biochar treatment, and that this promotion does not favor specific distribution sizes but is evenly distributed across fractions. A long term study reported an increase in soil aggregate size following the addition of biochar with NPK fertilizers. This combination increased the proportion of macro-aggregates > 2mm by 199% compared to the NPK treatment by itself. It also increases mean weight diameter and also reduced the relative proportion of micro-aggregates <0.25 mm (Du, Zhao, Wang, & Zhang, 2016; Ma et al., 2016). In terms of individual size fractions in this study for almost all treatments the total average proportion of aggregates declined from 0.25 mm size to 4 mm size with 4 mm fraction being the least prominent and 0.25 mm fraction the most prominent. The only exception to this trend was with alfalfa meal with biochar addition where the 4 mm sized aggregates were the most prominent in terms of overall proportions. Alfalfa meal without biochar exhibited a less prominent increase in the 4 mm fraction compared to alfalfa meal with biochar. While prominence of the 4 mm fraction in alfalfa meal is interesting this prominence was not statistically significant. In terms of nitrogen form the sterilized chicken manure treatment was significantly higher in terms of overall average proportion of aggregate fraction above 0.25 mm than all other nitrogen treatments when data for biochar and no biochar were combined. Sterilized chicken manure showed the greatest average aggregate fraction weight followed by alfalfa meal, ammonium nitrate, and then chicken manure. With biochar addition the sterilized chicken manure was significantly different in terms of the average proportion of aggregates above 0.25 mm compared to chicken manure. This may indicate that the microbial component in the chicken manure may be inhibitory towards the aggregation process and that the biochar addition may tend to enhance that difference (p value for biochar x nitrogen form interaction, 0.0078). There are no prior reports in the literature to our knowledge showing a microbial component in a manure decreasing overall aggregation.

CHAPTER VI

CONCLUSIONS

In general, there was no statistical differences across biochar and no biochar treatments in grain yield, percolation, penetration resistance and bulk density. Penetration resistance showed inorganic nitrogen fertilizer (ammonium nitrate) and plant based organic fertilizer (alfalfa) had the highest resistance to penetration compared to chicken manure and sterile chicken manure. Water-stable aggregate distribution showed a significant difference in soils treated with biochar with an increase of 13% in average aggregate distribution.

There were few consistent patterns associated with biochar and nitrogen form addition across season of growth and development notably in penetration resistance and water-stable aggregate distribution compared to the other properties measured. This may be due to confounding effects of the different methods used to grow the plants, the temperature differences associated with either fall or spring cultivation in the greenhouse, and having only two seasons of growth and development. Further research with greater replication will likely elucidate more subtle effects of biochar and different nitrogen fertilization methods.

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FIGURE LEGENDS

Figure 1: Seed grain yield per plant from wheat plants grown with different nitrogen forms in the presence or absence of biochar over two seasons of growth and development. Treatment differences visualized with different letters were analyzed based on analysis of variance with mean separation using Tukeys HSD with P values $\leq$ 0.05. Without lettering indicates no significant difference. Seasons were analyzed separately.

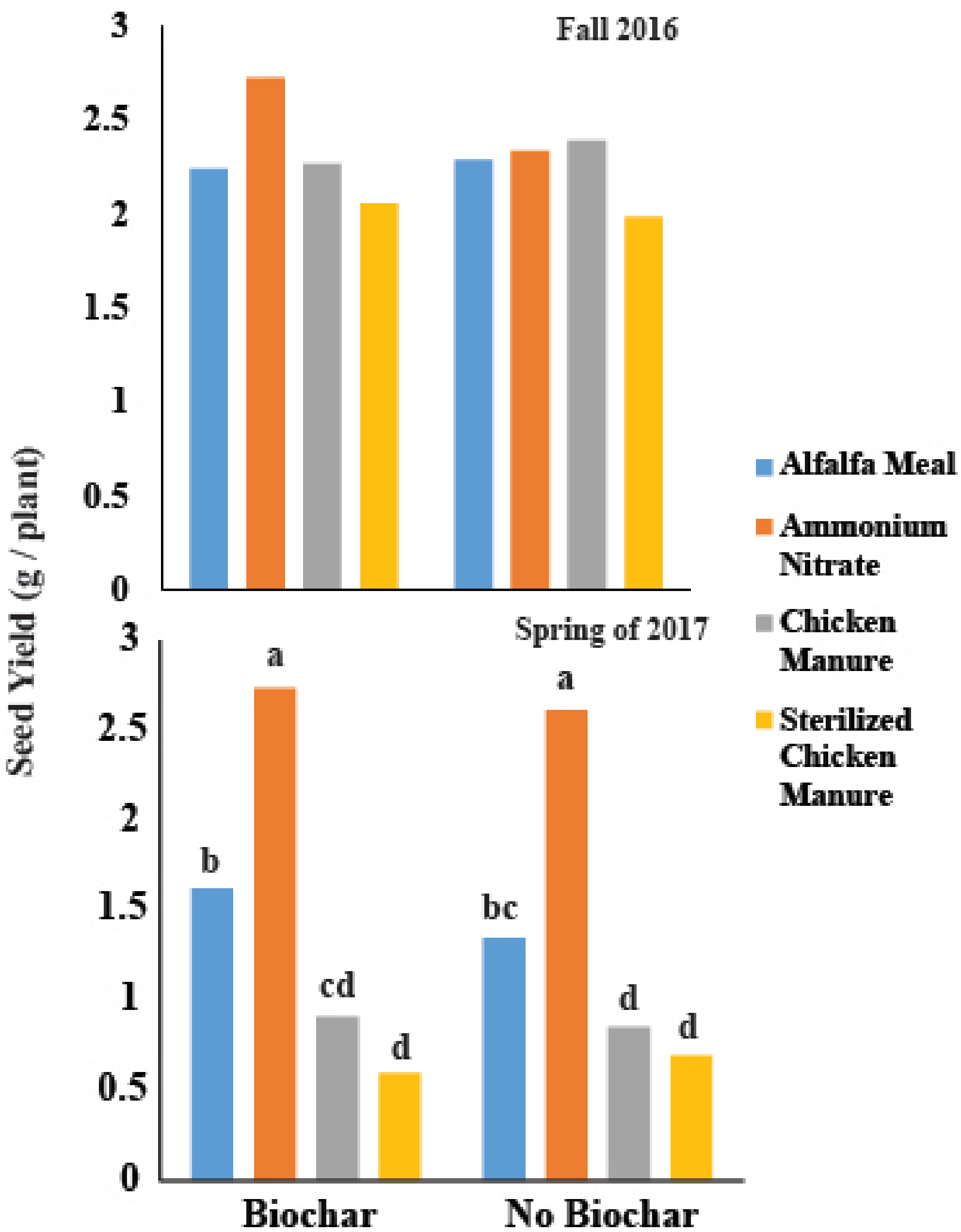
Figure 2: Bulk density of the soil treated with different nitrogen forms in the presence or absence of biochar over two seasons of growth and development. Treatment differences visualized with different letters were analyzed based on analysis of variance with mean separation using Tukeys HSD with P values $\leq$ 0.05. Without lettering indicates no significant difference.

Figure 3: Penetration resistance of soil treated with different nitrogen forms in the presence or absence of biochar over two seasons of growth and development. Treatment differences were analyzed based on analysis of variance with mean separation using Tukeys HSD with P values $\leq$ 0.05. There were no significant differences with season so data for season was combined for this analysis.

Figure 4: Percolation resistance results of soil treated with different nitrogen forms in the presence or absence of biochar over two seasons of growth and development. Treatment differences were visualized by a different letter and were analyzed based on analysis of variance with mean separation using Tukeys HSD with P values $\leq$ 0.05. Without lettering indicates no significant difference.

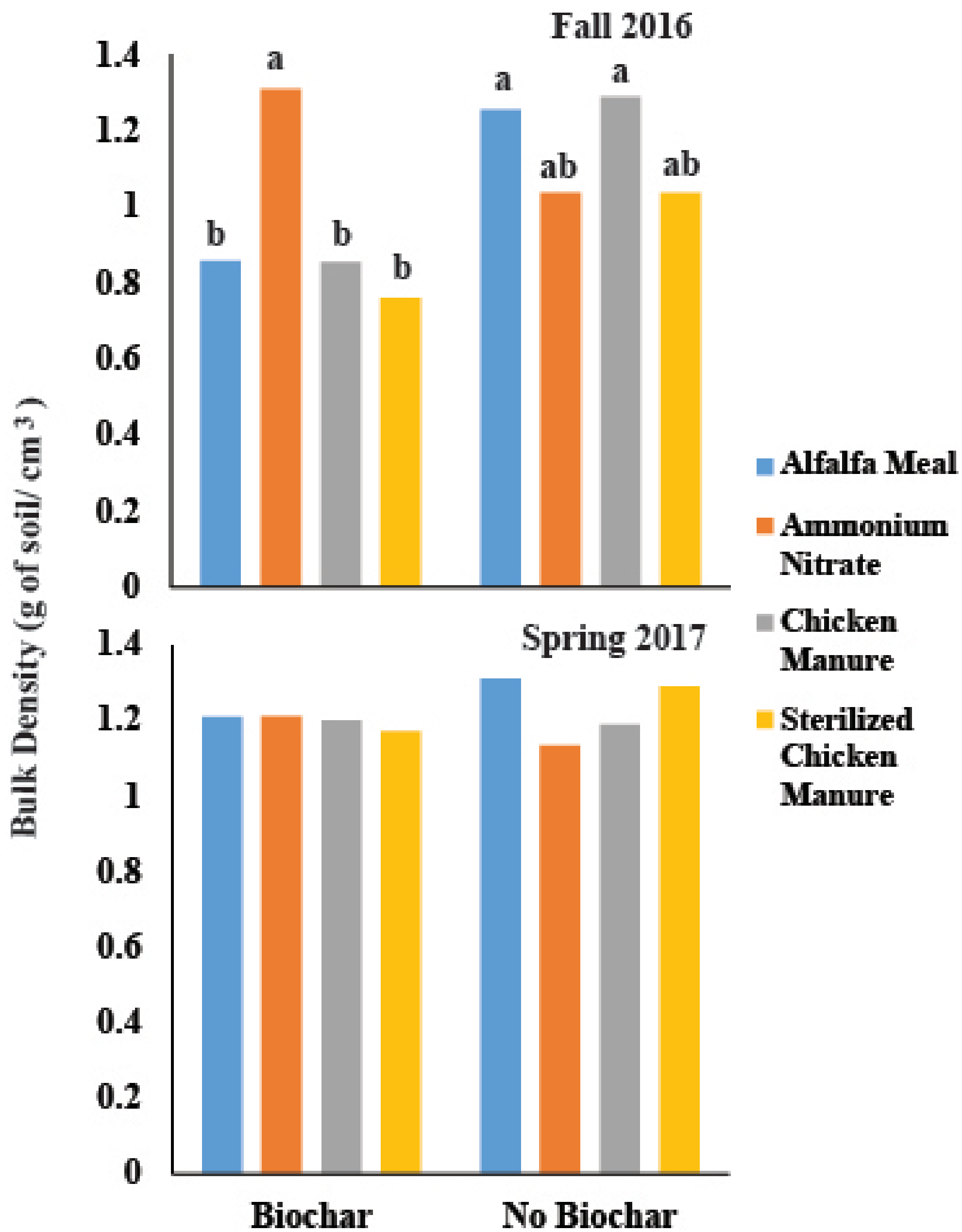
Figure 5: Aggregate distribution results of soil treated with different nitrogen forms in the presence or absence of biochar over one seasons of growth and development. Treatment differences were visualized with different lettering and analyzed based on analysis of variance with mean separation using Tukeys HSD with P values ≤ 0.05. Capital letters above each Biochar by Nform treatment indicates a significant difference.

Figure 1



Fall 2016
Spring of 2017
Seed Yield (g / plant)
3
2.5
2
1.5
1
0.5
0
a
b
cd
d
a
bc
d
d
Biochar
No Biochar
Alfalfa Meal
Ammonium Nitrate
Chicken Manure
Sterilized Chicken Manure

Figure 2



Fall 2016
Spring 2017
Bulk Density (g of soil/ cm^3)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
a
b
ab
Biochar
No Biochar
Alfalfa Meal
Ammonium Nitrate
Chicken Manure
Sterilized Chicken Manure

Figure 3

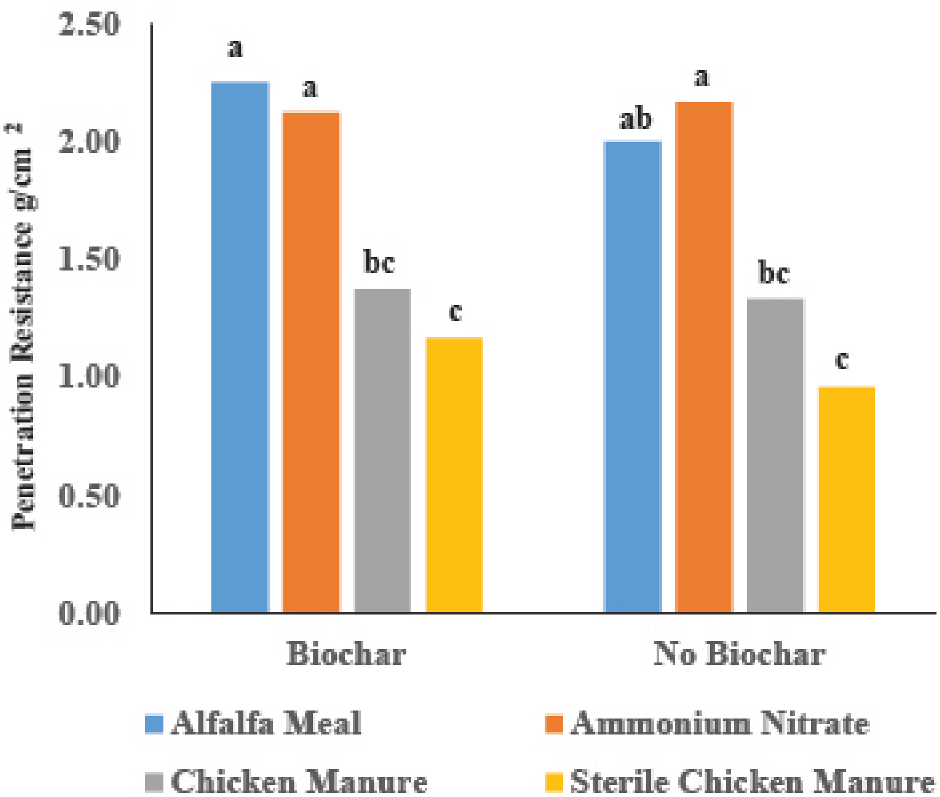

2.50
2.00
1.50
1.00
0.50
0.00
Penetration Resistance g/cm 2
a
a
bc
c
ab
a
bc
c
Biochar
No Biochar
Alfalfa Meal
Ammonium Nitrate
Chicken Manure
Sterile Chicken Manure

Figure 4

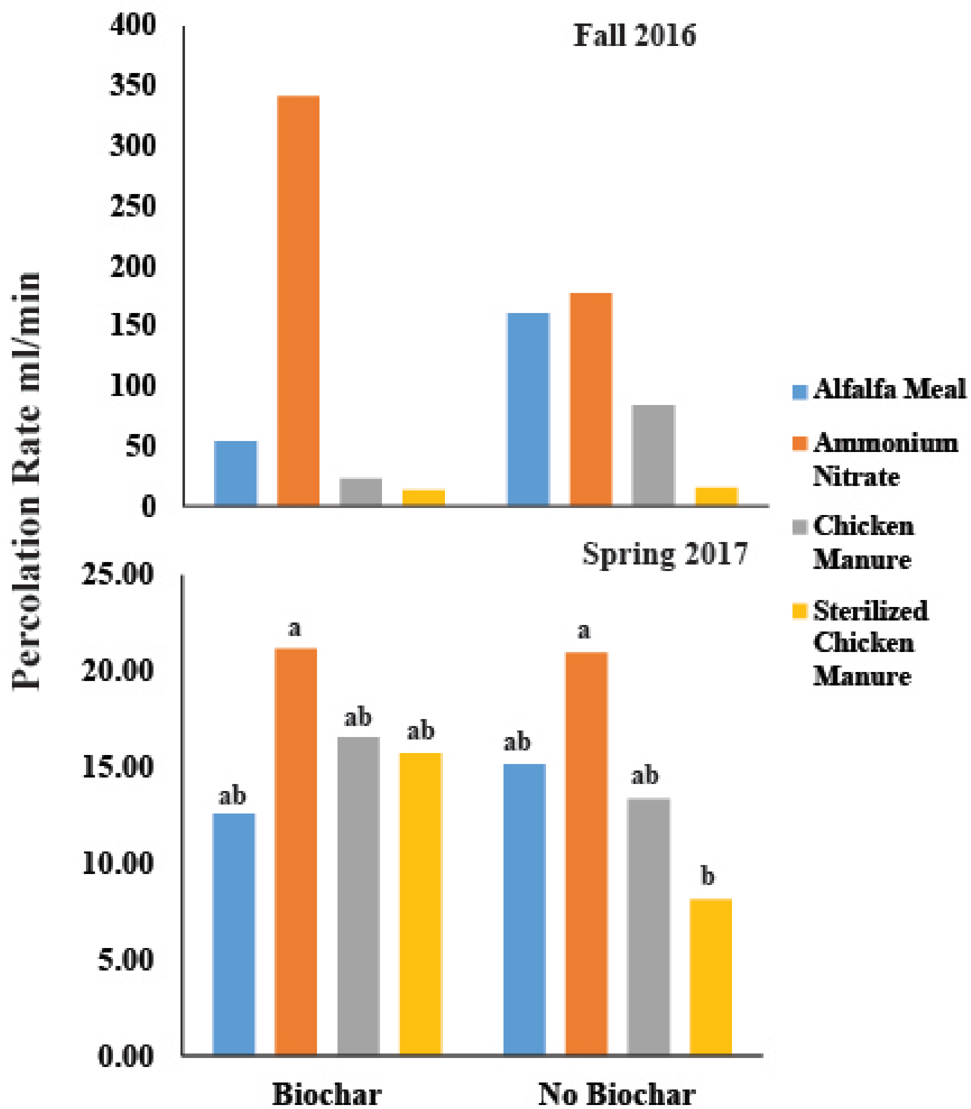
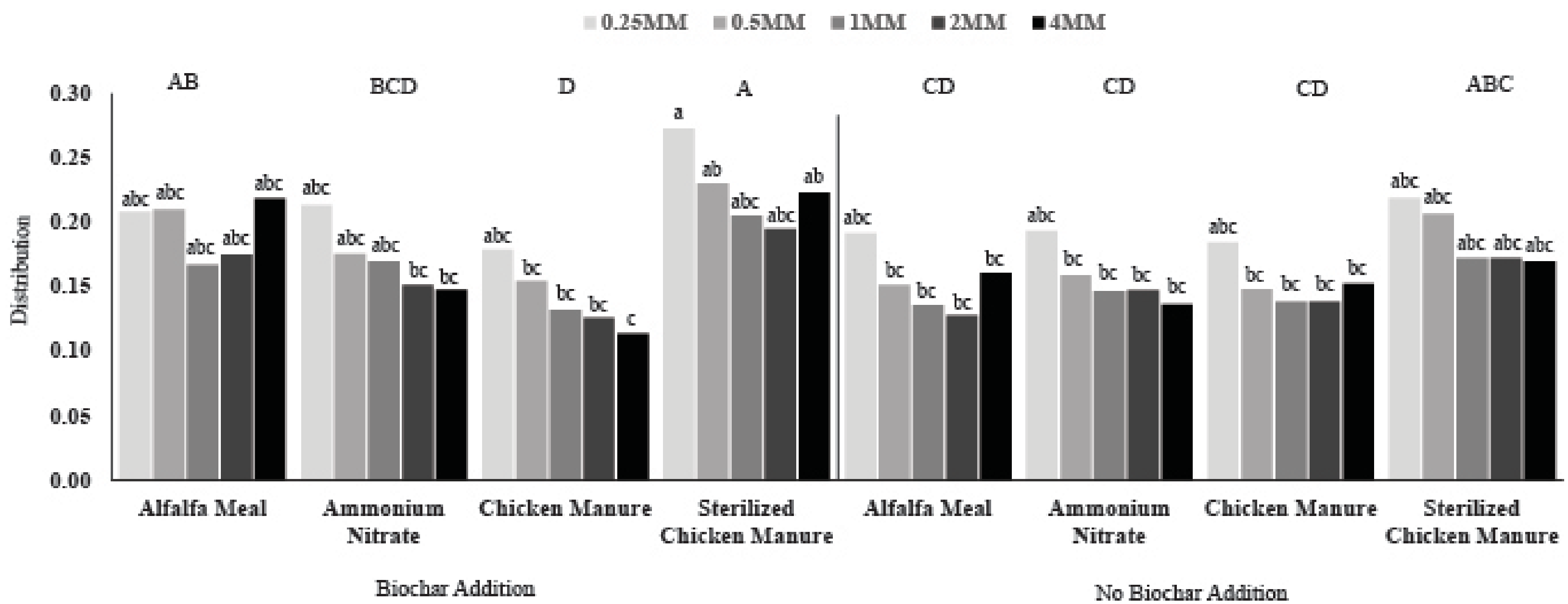

Fall 2016
Spring 2017
Percolation Rate ml/min
400
350
300
250
200
150
100
50
0
25.00
20.00
15.00
10.00
5.00
0.00
a
ab
ab
ab
a
ab
ab
b
Biochar
No Biochar
Alfalfa Meal
Ammonium Nitrate
Chicken Manure
Sterilized Chicken Manure

Figure 5



0.25MM
0.5MM
1MM
2MM
4MM
Distribution
0.30
0.25
0.20
0.15
0.10
0.05
0.00
AB
BCD
D
A
CD
CD
CD
ABC
abc abc abc abc abc
abc abc abc bc bc
abc bc bc bc c
a ab abc abc ab
abc bc bc bc bc
abc bc bc bc bc
abc bc bc bc bc
abc abc abc abc abc
Alfalfa Meal
Ammonium Nitrate
Chicken Manure
Sterilized Chicken Manure
Alfalfa Meal
Ammonium Nitrate
Chicken Manure
Sterilized Chicken Manure
Biochar Addition
No Biochar Addition

VITA

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